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“It's like a giant brain with a keyboard”

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“It’s like a gigantic brain with a keyboard”: why we should teach children how computers work

Abstract

In a qualitative study, a follow up to a similar study conducted 30 year previously, we asked children aged between 5 and 8 about their knowledge and beliefs about computers. Although the children were insightful in their answers about the activities for which it might be appropriate to use technology, and willingly engaged with the thorny question of whether computers can think, their responses indicated a lack of a factual understanding of how computers work. Consequently, this paper argues that children should be taught basic information about how computers work because they will not become aware of this through regular exposure to technology. The paper offers some simple explanations of how computers work, and whether computers could think, which we hope will be of use to practitioners who wish to cover these topics in their classrooms.

Introduction

Thirty years ago, our colleagues at the University of [blank for review] interviewed a large group of primary school aged children from two schools about their ideas about computers during a time of transition when personal computers first became available in homes and schools (Hughes, Brackenridge, & MacLeod, 1987). The children were asked about their attitudes to computers, their conceptions of how they function and their beliefs of the agency of computers. The authors wanted to gather baseline data about “computer-naïve” children’s ideas about computers to facilitate study of changes in children’s ideas as technology advanced. An important aspect of this was to ascertain children’s conceptual models of how

computers operate. Hughes et al. argued that if learners have an inadequate or flawed conceptual model of how computers work, although they may acquire low level skills, they will be hampered in generalising or deepening those skills. They suggested that explicit instruction about how computers work would be beneficial in order to assist children in acquiring accurate conceptual model appropriate for learning to program. Beyond the idea that attributing too much intelligence to a programming language might be hazardous to one's programming ability, there were wider debates at that time among philosophers of artificial intelligence about the possible dangers of people anthropomorphising machines.

Hughes, Brackenridge and MacLeod found that children were excited and interested in the new technology but that they had a limited understanding and flawed mental models of how they worked. Since Hughes et al. published their findings, the technological landscape of our lives has changed remarkably. In their first study, two thirds of the children had never used a computer. The World Wide Web had not yet been invented, and smart phones did not exist. In 2015, 86% of children in the 5-15 age group in the UK had access to a desktop or laptop computers at home, and 81% had access to a tablet computer (Ofcom, 2015). Most children in the UK now have grown up with easy access to technology, if not at home, then most probably at school. The importance of educating children about computing has now been internationally recognised (Furber, 2012), with an emphasis on an underlying approach to solving problems called computational thinking (Grover & Pea, 2013). In addition to computational thinking, from the perspective of developing children's conceptual understanding, we think it is important that learners are aware of the limitations of the machine architecture and how it is very different from how human brains think. The knowledge that instructions in computer software are carried out with laborious pedantry by a processor on the basis of a long string of 0s and 1s, builds awareness that computers are not capable of magically performing intelligent feats on their own.

It is important for children to understand what computing technology is capable of, both currently and potentially in the future. In relation to the current capability, they can be made aware of how technology is integrated into the world around them, e.g. in automatic doors, electronic cars and toys, and in computer games. Where it is hidden, they can learn to infer the capability of the technology from its behaviour. Being able to answer questions such as: ‘How does that toy know who I am? Why has my phone recommended this friend? Why does that automatic door keep opening?’ will benefit them both in their everyday life, and in the workplace. Knowledge of digital devices in their environment can empower children, making it easier to predict and control their lives.

Computer architecture has remained relatively static in the last thirty years – the main components in a modern computer and the way in which these are interconnected is still based on the von Neumann architecture from 1945. This means that explanations of how computers work in 2016 and how they worked in 1985 are very similar, particularly at the level of detail which would be suitable for children. This might seem surprising, given the advances in computing technology with which we are familiar. The reason for this is that the processing power available on chips has grown exponentially, following Moore’s Law. This means that the computer chips used in consumer devices today are much faster and therefore able to process large amounts of information in a feasible timescale. Sophisticated statistical algorithms, working on the huge datasets which are now available, have the necessary processing power to solve previously intractable problems such as automatic face recognition, speech recognition and automated vehicle control. While machines are now capable of making decisions based on statistical inferences, explanations and justifications for these decisions are often not available in a form which is easy for people to understand.

Like Hughes and colleagues, we do not believe there is currently a “correct” answer to the question of whether computers could think. We do believe that it is important for children to

engage with questions that relate to legal and ethical aspects in an informed and thoughtful way, supported by knowledgeable adults. In a society which relies so heavily on technology, children have a right to know the strengths and limitations of that technology and a responsibility to consider the potential risks and implications of how the technology may evolve. To reason realistically about possibilities and pitfalls of future technologies, including artificial intelligence, they require some knowledge of the basics of computer architecture: *how* does a machine follow instructions and how can intelligent seeming behaviour arise from such simple instructions?

What children already know and believe about computers

In order to understand what children today know and believe about computers, the authors interviewed eighteen children aged between 5 and 8 (eight boys) from two state funded primary schools in a Scottish city.

The children participated in pairs in semi-structured interviews for around 30 minutes, based on the questions from (Hughes et al., 1987) with additional questions about societal uses of current technology.

The interviews were video recorded and transcribed. Thematic analysis was performed by the 1st author on the transcriptions using NVivo 10. The themes, chosen in advance, were related to the interview questions as shown in Table x. All names have been replaced by pseudonyms.

Table 1. Interview questions and themes

Themes	Question
Understanding what computers are	What do you think a computer is?
	What do you think computers do?
	What do you think is inside a computer? <i>Point to image of a PC</i>
	<i>Show children a picture of a computer chip and explain that is what is inside</i>

	Where else do you think you might find computer chip?
Understanding how computers are programmed	How do you think computers work?
	How do you think a computer knows what to do?
	<i>Interviewer: A computer knows what to do because it follows some instructions.</i>
	How do you think we give the computer instructions?
Beliefs about whether computers have agency	Do you think computers want to do things?
	Do you think computers think?
	Do you think computers thinks as we do?
	Do you think computers are better at thinking than we are?

Results

Understanding what computers are

When asked: “What is a computer?”, the children tended to either define it by the activities which it enabled them to perform (such as watching YouTube, playing games, typing, searching or downloading files) or in comparison to other electronic devices.

The children described a range of purposes for a computer in answer to the question: “What do you think computers do?”, including visiting websites, playing games or music, shopping, doing homework, writing, sharing pictures and sending messages. Sophia (School B, P4) noted: “They could help you ... if you didn't have a phone, or anything, you could use a computer to search”. The children also believed that computers could have educational purposes: including assisting with research and spell checking. Ruth (School A, P2) revealed that Santa makes use of computers: “When it comes to Christmas you might be able to watch ... if you’re on the good list or bad list.”

In response to the question “What’s inside a computer?”, the most common answers mentioned batteries and wires. Alice (School B, P2) said: “a wire that helps the computer work.” When asked what this looked like, she responded: “sort of like a fridge.” However,

Rorie also correctly realised that it would have: “a memory of the stuff you type in.” Donald (School A, P1) said inside the computer there would be: “a big long bit where... you can plug in one side.” He also thought there might be music inside. None of the children appeared confident or detailed in their answers.

Finally, when the interviewer showed the children a picture of a computer chip and asked them where else chips could be found, they identified a range of devices including tablets, phones, video cameras, traffic lights, clocks and watches.

Understanding how computers are programmed

The younger children found it hard to answer the question “How does a computer work?”.

They commonly mentioned wires, switches, plugs or stated the word “chips” which they had just learned about in the previous part of the interview.

Even the older children found this question difficult. They enumerated parts of the computer such as hard drives, discs, cables and mechanical components such as switches, buttons and levers. Catriona’s answer is indicative of the confusion the children exhibited “I’m not quite sure.... It’s hard to sort of describe it... Well, sometimes when I’m using something I think, ‘is there someone inside this - that’s just slipped in?’ but no, probably not.” (Catriona, School A, P5).

The children were also unsure when asked “how does a computer know what to do?”. After Louise (School A, P4) suggested that the computer might have a brain, David expanded on this idea “it’s like a gigantic brain just basically with a keyboard. Think of this - your brain with a keyboard just writing your password into a lock - it remembers the password. So, if your brain was in a lock, basically connected to the brain, the brain would open the cage to let you get it.” Although David is valiantly trying to make sense of a complex system by using two analogies (brain and lock), he would benefit from an accurate factual explanation from a

teacher. Sophia (School B, P4) offered a correct explanation at a more abstract level of description “I think people have programmed it to do what you ask it to do.” Charlie (School A, P3) gave an answer which attempts to make a connection between the keyboard and screen hardware and the user’s key presses: “I’m not entirely sure about that, because by the keyboard they make it down for a press ... There’s like cables underneath there, I think. And then that takes all the way up to the screen, like if you were Googling something, or researching something. All the cables go in there from everything – like the ‘x’ the ‘Go’ and all the letters...”. Catriona (School A, P5) suggested: “it can sort of feel your hand, or something, like when you’re typing it up.”, which is perhaps the beginning of an explanation of how a touch screen interface might work.

The younger children gave simpler answers, mostly related to user input such as the mouse, joystick or keyboard - “Maybe they [computers] know because they have noticed you’re typing in.” (Eva, School B, P2). Rorie (School B, P3) thought that you could give instructions by talking to it, which is not unreasonable in the age of voice interfaces on consumer devices.

Beliefs about whether computers have agency

Five of the children thought that computers want to do things. The younger children were more likely to believe this, sometimes attributing a desire to be helpful to the computer (e.g. “They want to help you do games” Leila, School B, P1). Eight of the children thought that computers do not want to do things, and four were unsure or thought it depended on the circumstances. The children interpreted this question in different ways. Some children evidently thought that computers were *capable* of wanting but could be prevented carrying out their intentions “because they might have enough energy, and enough network to do it” (Alice, School B, P2) or because “they get freeze all the time” (Rorie, School B, P3). Having considered the matter from the computer’s point of view, David thought that they might be justified if they were reluctant to perform tasks: “imagine getting pressed... getting fingers

swiped across you, and getting ... stuff appearing on you - it wouldn't feel nice.” (David, School A, P3). He also speculated that the computer would be pleased to be thanked by its user and would respond by being more helpful. Some of the older children said that the computers could not have feelings and would do only what they were programmed to do. Freddie explained: “... they don't really have a choice not to do it. I think it sort of has to do it..” (Freddie, School A, P5).

When asked whether computers can think, six of the children who responded said “yes”, and five replied “no”. Four of the children who said that computers could not think pointed out that it does not have a brain. Catriona said gave a more detailed answer: “Basically, a person has to sit there and do something to the computer and the computer has to pop it up on screen. It can't really think, ‘should I do that? Or should I not do that?’ It ... just does it.” (Catriona, School A, P5). In contrast, Ollie believed that computers can think: “cos when they load, they're thinking. Cos sometimes they don't want to do things, it just goes: ‘no connection’, or something like that” (Ollie, School A, p2). David also argued that computers can think: “because, if you're thinking of the alphabet, it's thinking about the alphabet... You're thinking of a game, it's thinking of a game... You're thinking of facts, it's thinking of facts “(David, School A, P4).

If asked, the children generally thought that computers do not think in the same way as us. Alice mentioned that computers would think differently to us “because they've got wires that can help them think, too... and the wires think about computers” although these wire “don't think that hard” (Alice, School B, P2). Some of the younger children became quite competitive when discussing whether computers think like us. The primary ones from School B were adamant that they personally could think better than computers, while Holly proudly noted that: “they can't think better than my sister” (Holly, School A, P1).

Conclusions and Implications

The interviews give a picture of the extent to which children understand the technology which they encounter in their everyday lives. In spite of their knowledge and experience of using computers, they generally did not know how computers work, or how they might be programmed. The children had mixed views about the agency of a computer. Some of them thought that it was necessary to have a brain in order to think and therefore that computers could not think, while others thought that computers could think, on the basis of reasoning about the behaviour of a computer as if it were a person. Others believed the computer could only follow instructions.

Technology is rapidly changing. In the thirty years since Hughes and colleagues carried out their study, children's access to technology has expanded hugely – they now routinely benefit from the Internet, powerful mobile devices, satellite navigation, and speech interfaces. Yet, the children of the present study displayed a strikingly similar lack of understanding of how a computer works to their counterparts in the 1980s. Both groups spoke of electrical components such as wires, plugs and batteries but did not display deeper understanding of how it functions. In the previous study, the children were inclined to believe that computers could think, although as with the present study, some also believed that computers could not think because they did not have a brain. There was a similar pattern of responses when children were asked whether computers want to do things – in both studies the children who interpreted this in terms of the computer's willingness to do things agreed that they do, and there were also children in both studies who identified that the computers did not have desires and were only capable of following instructions. It would seem that children's conceptions of how computer work, and their theories of computer mind are not more advanced now in spite of their far greater exposure to more sophisticated technology.

The children we interviewed in this study were able to speak intelligently about how they used computers, and tried hard to explain how computers might work. However, they found this difficult because they were lacking basic factual knowledge about computer system in terms of hardware and software. We had some fascinating discussions about whether computers could think. The children were interested in these ideas, and showed some insight into theories of mind – in this case the mind of a non-human “other”. We believe that children should have opportunities to discuss deep open ended questions where there are no correct answers – such as what is the nature of intelligence? – but that these discussions are richer if the children are informed and knowledgeable about the subject matter.

Practitioner guidance: What children need to know about how computers work

To aid practitioners who wish to teach computing concepts to their learners, the following sections give brief explanations of what is inside a computer, how it follows instructions and whether computers could ever think for themselves.

What’s inside a computer?

*There’s an electronic **chip** inside every computer, laptop, tablet or phone (see Figure 1). The chip needs power to work, which is why you need to plug in your computer, or charge the batteries of your tablet. The chip contains a **processor** which is like the computer’s brain. It also has **memory** for storing information it is working on now, and a **hard drive** for information it will need to store for a long time. The processor has got billions of little electronic switches inside it. The switches can each be set to “off” or “on”. The computer has instructions in its memory which tell it what to do. The messages are written in **binary code** which means they only contain 1s and 0s. A “1” means “turn a switch on”, and a “0” means “turn a switch off”. When you type, the keyboard sends a message to the processor*

about which key you have pressed and the processor uses the instructions in its program to decide what to do.

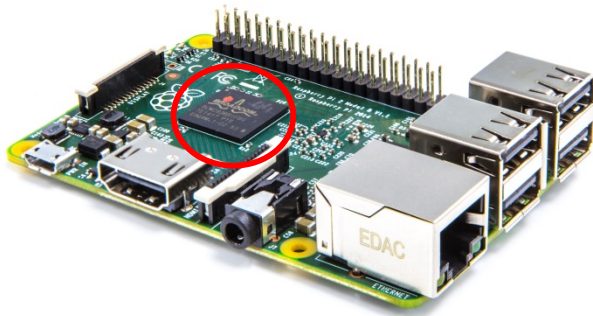


Figure 1. Inside the Raspberry Pi computer. The chip is circled in red.

What does a computer do when it follows instructions?

*Imagine you have written a program in Scratch which adds together two numbers. When you press the green flag icon to make your program run, how does the computer follow the instructions you have written? Scratch is designed to be easy for people to learn using words and pictures we can understand. The computer processor works with binary code but it would be very confusing for people to have to write instructions all in 1s and 0s. So programs written in Scratch or other **high level languages** get translated before they run on the processor. When you press a particular icon (the green flag) to tell Scratch to run your program, the computer follows rules which eventually turn your jigsaw blocks into binary code instructions which the processor can follow by turning its switches on and off. Once it has worked out the answer to the sum you have, the answer is translated from binary code and passed back to Scratch to show on the screen.*

Could a computer think?

Most people would agree that the computers we use every day don't think for themselves in the way that people do– they follow instructions which people have given them. Sometimes it

seems like the computer or phone is more clever than it really is, especially if you are using a program which seems to understand what you say. Computers are good at calculating, searching huge amounts of information very quickly and accurately and sometimes making decisions based on the information. Humans are not so good at this sort of task, but we're usually much better than computers at working out answers to new problems, being creative and understanding feelings.

*Scientists and engineers who research **artificial intelligence** have been trying to make intelligent machines since the 1950s. Because of their work, your phone can recognise what you say to it, satellite navigation programs ("Sat Nav") can speak directions out loud, robots (such as the Mars Rover) can navigate for themselves, and even the best human chess players can be beaten by a computer. Although these programs are impressive, they can't do all of the many amazing things which even young children can do. Activities which we take for granted, such as walking, understanding how your friend feels or learning new languages turn out to be surprisingly hard to program into computers.*

Could computers in the future think for themselves? And if they did, would they be friendly to humans, or would they want to wipe us out? Nobody really knows yet, and experts disagree about it. But it is worth thinking hard about it today because it may be possible to design intelligent computers for the future which can help us to make Planet Earth a fairer, safer and more interesting place to be.

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